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ORIGINAL ARTICLE

# Personal and workplace psychosocial risk factors for carpal tunnel syndrome: a pooled study cohort

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## ABSTRACT

**Background** Between 2001 and 2010, six research groups conducted coordinated multiyear, prospective studies of carpal tunnel syndrome (CTS) incidence in US workers from various industries and collected detailed subject-level exposure information with follow-up symptom, physical examination, electrophysiological measures and job changes.

**Objective** This analysis of the pooled cohort examined the incidence of dominant-hand CTS in relation to demographic characteristics and estimated associations with occupational psychosocial factors and years worked, adjusting for confounding by personal risk factors.

**Methods** 3515 participants, without baseline CTS, were followed-up to 7 years. Case criteria included symptoms and an electrodiagnostic study consistent with CTS. Adjusted HRs were estimated in Cox proportional hazard models. Workplace biomechanical factors were collected but not evaluated in this analysis.

**Results** Women were at elevated risk for CTS (HR=1.30; 95% CI 0.98 to 1.72), and the incidence of CTS increased linearly with both age and body mass index (BMI) over most of the observed range. High job strain increased risk (HR=1.86; 95% CI 1.11 to 3.14), and social support was protective (HR=0.54; 95% CI 0.31 to 0.95). There was an inverse relationship with years worked among recent hires with the highest incidence in the first 3.5 years of work (HR=3.08; 95% CI 1.55 to 6.12).

**Conclusions** Personal factors associated with an increased risk of developing CTS were BMI, age and being a woman. Workplace risk factors were high job strain, while social support was protective. The inverse relationship between CTS incidence and years worked among recent hires suggests the presence of a healthy worker survivor effect in the cohort.

## INTRODUCTION

Carpal tunnel syndrome (CTS) is a common peripheral entrapment neuropathy resulting from compression of the median nerve under the transverse carpal ligament at the wrist. CTS is an important driver of workers' compensation costs, lost time, lost productivity and disability.[1 2] Although not as common as other upper extremity disorders, CTS is an important occupational health problem because of higher disability and overall costs than virtually any other upper extremity disorder.[3] Prior studies have related CTS to both personal and occupational risk factors,[4–8] however, the strength of these associations and the exposure–response relationships are not well described.[1] To date, few large prospective studies using rigorous case criteria, individual-level exposure data, and appropriate control for confounding by personal factors have examined associations between occupational psychosocial and biomechanical risk factors and CTS incidence.[7] To address this and other gaps in the literature, six research groups designed coordinated, multiyear, prospective epidemiological studies of US production and service workers from a variety of industries. Subsequent to completion of the studies, data on detailed subject-level exposure information was pooled with longitudinal assessment of symptoms, physical examination results, electrophysiological measures and biomechanical factors due to job changes.[9] In the current manuscript, we describe the relationships between personal factors, occupational psychosocial factors and duration of employment, with CTS incidence, while adjusting for effects of confounding variables. Workplace biomechanical factors were collected and will be presented in a future paper, and thus, are not included in these analyses.

Population-based CTS incidence rates have ranged from 0.23 per 100 person-years[10] to 11 per 100 person-years depending on study sample, occupational sectors and case definitions.[11 12] Although numerous studies have identified associations between occupational risk factors, such as high hand force and repetitive hand activities and CTS,[13–15] relatively few studies have assessed the role of occupational psychosocial factors.[16–18] Moreover, variability in CTS case definitions have limited comparisons of results across studies.[19] Thus, relatively little is known about how occupational psychosocial factors (such as job strain) and work organisational factors independently contribute to the risk of CTS.[20]

Associations between CTS and age, female gender, pregnancy and body mass index (BMI), have been reported in numerous studies.[21–25] However, detailed descriptions of the exposure–response relationships between these personal risk factors and CTS are not available, especially for occupational cohorts. In addition to demographic characteristics, comorbid conditions, such as rheumatoid arthritis,[23 26] diabetes mellitus[23 26–28] and thyroid disease,[24 29] have also been associated with CTS risk. Associations between CTS and

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other risk factors, such as gout and smoking status are uncertain[26] and have not been assessed with adequate power in occupational studies.

In the current analysis, we examine associations between personal demographic and health characteristics, occupational psychosocial stress and work organisational factors, and incident CTS in a large cohort of industrial workers. In addition, the healthy worker survivor effect[30] has rarely been taken into account in studies of musculoskeletal injuries, though a study of CTS may be particularly vulnerable to this bias depending upon the extent of the associated morbidity. If workers highly exposed to repetition and forceful movements, for example, are more likely to leave the workforce due to CTS symptoms, then the remaining exposed workers may have lower risk of developing CTS. Therefore, a secondary aim was to examine evidence for healthy worker bias in this first report of a pooled prospective cohort study of CTS.

## METHODS

### Study participants and procedures

#### Participants

The 4321 individuals in the current analyses were recruited into six prospective epidemiological studies of risk factors for work-related upper-extremity musculoskeletal disorders (UEMSDs) conducted between 2001 and 2010. Details on each study design, health outcome pooling methods and baseline CTS prevalence are provided elsewhere.[9] Common inclusion criteria were: (1) full-time work in industries primarily engaged in manufacturing, production, service and construction and (2) availability of individual-level exposure information. This analysis was restricted to the 3515 participants for whom follow-up data were available and who did not have baseline CTS or previous carpal tunnel surgery release (n=338), or baseline polyneuropathy (n=58).[9] There was varied representation of workers across standard industrial classification (SIC) divisions with the majority of subjects coming from the manufacturing (n=2256), services (n=673) and construction (n=335) sectors. Other SIC divisions represented included agriculture (n=148), wholesale trade (n=47) and retail trade (n=49).

#### Baseline information

In all six studies, questionnaires were administered at study enrolment (baseline) to collect information on work history, demographics, medical history and musculoskeletal symptoms. Survey or interview questions regarding the psychosocial work environment were administered either at study enrolment or at 6 months after being hired. Five of the six studies included items from the Job Content Questionnaire (JCQ)[31] necessary to calculate the psychological job demand and decision latitude scores. Five of six studies administered an electrodiagnostic study (EDS) of all workers' median and ulnar nerves at baseline, while one study administered EDS only to those reporting symptoms consistent with CTS. All studies administered physical examinations either to all subjects or for those reporting upper limb symptoms.[9] In all studies, investigators responsible for collecting health outcome information were blinded to exposure status.

#### Periodic follow-up

Symptoms were assessed at regular intervals during follow-up, though the interval length differed across the six studies. Physical examinations and EDS were administered either in response to positive symptoms or annually, depending on the particular study design.[9]

#### Electrodiagnostic procedures

Electrophysiologic measures obtained across the wrist included median nerve sensory latency, median nerve motor latency and ulnar nerve sensory latency. Four different recording devices were used, and the comparability of EDS methods has been described elsewhere.[9] All sensory latency values were normalised to a distance of 14 cm. All latencies (motor and sensory) were adjusted for measured skin temperature.[9] Latencies not quantifiable but clearly abnormal (ie, absent evoked response) were classified as abnormal.

### Measures

#### Personal and occupational psychosocial factors

All studies collected participant age, gender, height, weight, BMI, race/ethnicity, education, smoking status, hand dominance and comorbid medical conditions, such as rheumatoid arthritis and diabetes mellitus. Most studies also collected information about pregnancy status, gout and thyroid disease. Previous carpal tunnel release and disorders of the distal upper extremity were also assessed. The time spent engaged in non-occupational, non-aerobic hand-intensive activities (ie, knitting, gardening, housework) and non-occupational, aerobic, non-hand-intensive activities (ie, jogging, walking, swimming, basketball, soccer) was assessed at baseline and summed to provide the total number of hours spent in each category of activity per week. Neither variable included hand-intensive aerobic activity (ie, biking). General health was assessed on a 5-point scale.

Information on occupational psychosocial factors was collected at baseline or within 6 months of being newly hired, with scales from the JCQ. The JCQ psychological job demand and decision latitude scales were each dichotomised by splitting the distributions at their respective median values. The four-category job strain variable was created by assigning participants to one of the four quadrants resulting from the two split distributions (ie, high demand, low control; low demand, low control; high demand, high control; and low demand, high control).[31] The a priori putative high job strain was defined as the job strain quadrant characterised by high demand and low control. In addition to the demand and control domains, a dichotomous social support variable was created by summing the JCQ coworker and supervisor support scale scores, and then splitting the resulting distribution at the median. The self-reported years worked at the current employer at enrolment, and the total time enrolled in the study up to the endpoint (ie, loss to follow-up, censoring, or end of study) were summed and used as a surrogate for total exposure. For analyses comparing time on the job, recent hires were defined as those hired within a year of enrolment.

#### Outcome

The primary outcome was CTS of the dominant hand. The case definition for CTS required symptoms that met study criteria (below) and median neuropathy based on an EDS consistent with median nerve mononeuropathy at the wrist.[32 33] Symptom information was collected by survey or interview, and the symptom criteria were tingling, numbness, burning, and/or pain in one or more of the first three digits (thumb, index finger, and long finger) since the prior symptom collection date. The minimum requirement for triggering a physical examination was 'occurring three times or within the last seven days'. The symptom questions used have been shown to have good to excellent test-retest reliability[34 35] Median mononeuropathy was defined as temperature and distance adjusted: (1) peak median sensory latency >3.7 ms or onset median sensory latency >3.2 ms at 14 cm, (2) motor latency >4.5 ms, (3) transcarpal sensory difference of >0.85 ms (the difference in sensory latencies between the median and ulnar nerves across the wrist) and/or (4) an absent latency value consistent with an abnormal NCS. The latency thresholds for the pooled EDS data were determined by the consortium members prior to data analysis. Thresholds were selected based on the literature, and where there was a range, thresholds were selected that increased specificity.[9] Subjects who met the study case definition for CTS at baseline were excluded from analyses. Incident cases were those who met both symptom and EDS criteria concurrently during follow-up. Polyneuropathy cases were defined as those meeting CTS case criteria with concurrent temperature-corrected peak ulnar sensory latency >3.68 ms or onset ulnar sensory latency >3.18 ms at 14 cm. Polyneuropathy cases were censored at the time the polyneuropathy case definition was met, and were not included as CTS cases. Individuals who were symptomatic without a subsequent EDS were censored at their last date of known cases status.

### Statistical analysis

Dominant hand CTS incidence rates and crude incidence rate ratios (IRR) were calculated for each demographic and health-related factor, as well as for occupational psychosocial characteristics and years worked. HRs were estimated using Cox proportional hazards regression, with robust CIs, and adjusted for potential confounding. Years worked was categorised based on the distribution of cases to ensure an adequate number of cases in all categories. To account for left truncation bias due to follow-up of subjects hired before baseline,[36] we also stratified the analysis of years worked and CTS by date of hire; subjects hired within a year of enrolment were considered separately. Covariates, including age, gender, BMI and medical conditions were considered potential confounders. Confounding was assessed using a 10% change in coefficient criterion of the magnitude of the primary exposure effect. The interactions of gender and comorbidities (BMI ≥30 kg/m$^2$ or the existence of a comorbid medical condition) were assessed by stratification and inclusion of interaction terms in the models. The functional form of the relationship between CTS and age and BMI were assessed using penalised splines[37] in a Cox model (R Core Team, Vienna, Austria). All analyses were implemented with the Stata Statistical Package (Stata, College Station, Texas, USA).

## RESULTS

The baseline cohort included 4321 participants. After excluding prevalent CTS (n=338) and polyneuropathy cases (n=58) and those lost to follow-up (n=410), the pooled prospective cohort included 3515 individuals (table 1). Approximately half the cases were women, and just over half were less than 40 years of age. Eleven percent were college graduates (n=336) of which only 11 became incident cases. Most subjects in the pooled cohort had worked with their current employer for more than a year prior to enrolment (referred to as ‘non-recent hires’); the average years worked at baseline was 6.2 years (SD=8.2). A sizeable subset (n=1237), however, was enrolled within a year of hire (ie, ‘recent hires’) (table 2).

There were 204 (5.8%) incident cases of dominant-side CTS observed during the 8833 person-years of follow-up for an incidence rate of 2.3 (95% CI 2.0 to 2.7) per 100 person-years. Follow-up time across studies ranged from 2 to 7 years.[9] Twenty-eight individuals were censored due to the development of polyneuropathy, and 159 individuals were censored at their last time of known case status due to incomplete health outcome information (ie, positive symptoms without a subsequent EDS). To examine the temporal pattern of CTS development, we evaluated the baseline status of the 204 incident cases. Approximately 20% (n=40) of the incident CTS cases were both symptom free and had a normal EDS at baseline, while 63% (n=128) had an abnormal EDS with no symptoms, and 11% (n=22) had symptoms with a normal EDS. Fourteen cases had either negative symptoms or a negative EDS at baseline with the other criterion missing. By contrast, among non-cases,

**Table 1** Demographics and health-related characteristics

| | Total n=3515 | % |
|---|---|---|
| Gender | | |
| Male | 1860 | 53 |
| Female | 1654 | 47 |
| Age (years) | | |
| <30 years of age | 1089 | 31 |
| ≥30 and <40 years of age | 836 | 24 |
| ≥40 and <50 years of age | 933 | 26 |
| ≥50 years of age | 656 | 19 |
| Ethnicity | | |
| Caucasian | 1901 | 60 |
| Hispanic | 524 | 16 |
| African–American | 499 | 16 |
| Asian | 160 | 5 |
| Other | 89 | 3 |
| Education | | |
| Some high school or less | 572 | 16 |
| High school graduate or above | 2914 | 84 |
| Right hand dominant | 3205 | 91 |
| Body mass index | | |
| Body mass index (<30 kg/m$^2$: normal or overweight) | 2324 | 66 |
| Body mass index (≥30 kg/m$^2$: obese) | 1176 | 34 |
| General Health | | |
| Very good or excellent | 891 | 43 |
| Good | 897 | 43 |
| Fair or poor | 281 | 14 |
| Medical condition | | |
| No medical condition | 3164 | 90 |
| Current medical condition | 346 | 10 |
| Diabetes mellitus | 123 | 4 |
| Rheumatoid arthritis | 66 | 2 |
| Thyroid disease (hyper- or hypothyroid) | 159 | 5 |
| Pregnancy | 19 | 1 |
| Gout | 42 | 1 |
| Previous DUE MSD | | |
| No previous DUE MSD | 2559 | 90 |
| Previous DUE MSD | 297 | 10 |
| Smoking status | | |
| Never smoked | 1897 | 54 |
| Currently smoked | 1006 | 29 |
| Previously smoked | 596 | 17 |
| Weekly aerobic activity | | |
| >3 h/week | 1040 | 65 |
| ≤3 h/week | 548 | 35 |
| Weekly hand intensive activity (non-occupational) | | |
| >3 h/week | 727 | 34 |
| ≤3 h/week | 1399 | 66 |

DUE, Distal upper extremity; MSD, Musculoskeletal disorder

**Table 2** Summary of workplace factors

| | Total n=3515 | % |
|---|---|---|
| Total years worked (recent hires*) | | |
| ≤3.5 years | 517 | 42 |
| >3.5 years | 720 | 58 |
| Total years worked (full cohort) | | |
| ≤3.5 years | 755 | 22 |
| >3.5 years and ≤7 years | 1302 | 37 |
| >7 years and <=15 years | 886 | 25 |
| >=15 years | 551 | 16 |
| Job strain | | |
| Low job strain (low demand and high control) | 424 | 27 |
| Active (high demand and high control) | 308 | 20 |
| Passive (low demand and low control) | 364 | 23 |
| High job strain (high demand and low control) | 462 | 30 |
| Social support | | |
| Low support | 681 | 43 |
| High support | 895 | 57 |
| Physically exhausted | | |
| None to slightly physically exhausted | 1378 | 64 |
| Moderate to severely physically exhausted | 775 | 36 |
| Mental exhaustion | | |
| None to slight mentally exhausted | 1616 | 75 |
| Moderate to severely mentally exhausted | 549 | 25 |
| Job satisfaction | | |
| Very satisfied | 1172 | 38 |
| Satisfied | 1513 | 49 |
| Dissatisfied or very dissatisfied | 407 | 13 |

*Recent hire defined as hired within one year of study enrolment.

71% were symptom free with normal EDS, 21% had abnormal EDS only, and 8% had symptoms only. The adjusted HR for incident CTS among those with baseline symptoms only was 5.48 (95% CI 3.29 to 9.14), and for abnormal EDS only was 8.83 (95% CI 5.98 to 13.02). The mean years worked among the cases of the non-recent hires was 11.0 (SD=8.5) compared with 3.7 years (SD=1.3) in the subset recently hired. The crude incidence rate ratio comparing those hired more than a year before enrolment to those hired less than a year was 3.30 (95% CI 2.33 to 4.77).

Women had 1.7 times the CTS incidence rate of men (table 3), and a 30% increase in risk when assessed while adjusting for age and BMI (HR=1.3; 95% CI 0.98 to 1.72). Increasing age was associated with greater CTS risk; those over 50 years old had a CTS incidence rate more than three times that of those under 30 years of age. When assessed as a continuous variable, risk of developing CTS increased approximately linearly with age (see online supplementary figure S1). Above 50 years of age, the CIs widen due to sparse data. A BMI greater than or equal to 30 kg/m$^2$ almost doubled the risk of CTS (table 4) and, when assessed as a continuous variable, the HR increased approximately linearly with increasing BMI (see online supplementary figure S2). When each of four medical conditions (diabetes mellitus, thyroid disease, rheumatoid arthritis, pregnancy) was considered separately, they were all positively associated with CTS (except for pregnancy with zero cases), though only thyroid disease (IRR=1.81; 95% CI 1.01 to 3.01) was statistically significant (table 3). When the four medical conditions were combined and adjusted for gender, age and BMI, medical condition incurred no increased risk for developing CTS, and none of the conditions were statistically significant predictors of risk when analysed in separate adjusted models (table 4). There was no evidence for effect modification by gender of the associations with age, BMI, or medical condition.

In the cohort as a whole, the incidence of CTS either decreased or remained stable with years worked at the current company after adjustment for potential confounders, though the CIs were wide (table 5). When the analysis was restricted to those enrolled within one year of hire (eg, recent hires), the HR of 3.08 (95% CI 1.55 to 6.12) was significantly higher for those who worked up to 3.5 years (median time to become a case) compared with those who worked longer. The distributions of years worked were non-overlapping between recent and non-recent hires, precluding a direct comparison between the two subgroups.

Participants with a high psychological demand score had increased risk of CTS (HR=1.57; 95% CI 1.06 to 2.33), and those with high decision latitude had reduced risk (HR=0.73; 95% CI 0.51 to 1.04). Those with high job strain (high demand and low control) had a HR of 1.86 (95% CI 1.11 to 3.14) relative to those with low job strain (high control and low demand), and subjects with high social support had half the risk of incident CTS compared with those with low support (HR=0.54; 95% CI 0.31 to 0.95; table 5). There was no interaction between gender, BMI, or medical conditions with either job strain or social support on risk of CTS.

## DISCUSSION

This analysis provided a unique opportunity to assess the relationships between selected personal and workplace risk factors and CTS incidence with a larger sample size than most previous studies. The observed associations provide evidence for both modifiable and non-modifiable risk factors for CTS. The wide range of industries, jobs and locations represented in this cohort increases the generalisability of results. The CTS incidence rate in this worker cohort was 2.3 per 100 person-years. This incidence rate was higher than the 0.13 to 0.37 per 100 person-years reported from population studies,[38 39] and higher than the 0.17 per 100 person-years reported from workers' compensation datasets.[11] However, the incidence rate was at the low end of the range (1.2 to 11.0 per 100 person-years) of incidence rates reported by other prospective studies of working populations.[8 11 40] In this analysis, we identified a near-linear relationship between CTS incidence and both age and BMI. CTS incidence was also higher in categories with high job strain, and decreased with higher social support at work after adjusting for confounding by age, gender and BMI.

The adjusted HR effect size of 1.3 observed for women in the current study is lower than the approximate doubling of CTS risk observed in other studies.[41 42] A study by Silverstein[43] found that among those with median neuropathy, women reported more symptoms than men. This suggests that a reporting bias might explain the disparity in risk by gender. Another explanation for the increased CTS risk among women could be the physiological differences such as lower strength relative to task demands or stature.[7] A study by Violante *et al*[7] found that both men and women with taller stature and longer forearm length had 40–50% decreased risk compared with those with short stature and shorter forearm length. Violante *et al*[7] also found that gender was a particularly strong risk factor among those with high workplace exposures to forceful grip or repetitions. Given a woman's smaller stature and decreased strength, a task may require a greater percent of her maximum voluntary contraction than a male counterpart, and/or require greater

**Table 3** Incidence rate ratios for personal risk factors

| | Person-time (100 person-years) | Dominant hand CTS | Incidence rate (per 100 person-years) | Incidence rate ratio | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|---|---|
| Gender | 83.30 | 204 | | | | |
| Male | 39.41 | 81 | 1.85 | 1.00 | – | – |
| Female | 43.89 | 123 | 3.12 | 1.69 | 1.27 | 2.27 |
| Age (years) | 83.31 | 204 | | | | |
| <30 years of age | 29.18 | 32 | 1.10 | 1.00 | – | – |
| ≥30 and <40 years of age | 19.45 | 47 | 2.42 | 2.20 | 1.38 | 3.57 |
| ≥40 and <50 years of age | 20.28 | 69 | 3.40 | 3.10 | 2.01 | 4.88 |
| ≥50 years of age | 14.40 | 56 | 3.89 | 3.55 | 2.26 | 5.66 |
| Ethnicity | 77.01 | 183 | | | | |
| Caucasian | 47.42 | 126 | 2.66 | 1.00 | – | – |
| Hispanic | 9.43 | 16 | 1.70 | 0.64 | 0.35 | 1.08 |
| African–American | 14.28 | 25 | 1.75 | 0.66 | 0.41 | 1.02 |
| Asian | 3.42 | 9 | 2.63 | 0.99 | 0.44 | 1.94 |
| Other | 2.46 | 7 | 2.84 | 1.07 | 0.42 | 2.27 |
| Educational level | 82.82 | 200 | | | | |
| Some high school or less | 9.92 | 34 | 3.43 | 1.00 | – | – |
| High school graduate or above | 72.90 | 166 | 2.28 | 0.66 | 0.46 | 0.99 |
| Body mass index | 83.02 | 203 | | | | |
| Body mass index (<30 kg/m$^2$: normal or overweight) | 55.25 | 104 | 1.88 | 1.00 | – | – |
| Body mass index (≥30 kg/m$^2$: obese) | 27.77 | 99 | 3.56 | 1.89 | 1.42 | 2.52 |
| Overall health status | 43.73 | 161 | | | | |
| Very good or excellent | 20.59 | 55 | 2.67 | 1.00 | – | – |
| Good | 18.24 | 83 | 4.55 | 1.70 | 1.20 | 2.44 |
| Poor or fair | 4.90 | 23 | 4.70 | 1.76 | 1.03 | 2.91 |
| Medical condition | 83.16 | 204 | | | | |
| No medical condition | 75.21 | 176 | 2.34 | 1.00 | – | – |
| Medical condition | 7.95 | 28 | 3.52 | 1.50 | 0.97 | 2.25 |
| Diabetes mellitus | 2.75 | 7 | 2.56 | 1.08 | 0.43 | 2.26 |
| Rheumatoid arthritis | 1.49 | 6 | 4.02 | 1.66 | 0.60 | 3.69 |
| Thyroid disease | 3.77 | 16 | 4.24 | 1.81 | 1.01 | 3.01 |
| Gout | 1.16 | 6 | 5.17 | 2.23 | 0.81 | 4.94 |
| Previous DUE MSD | 74.85 | 158 | | | | |
| No previous DUE MSD | 67.17 | 127 | 1.89 | 1.00 | – | – |
| Previous DUE MSD | 7.68 | 31 | 4.04 | 2.13 | 1.39 | 3.18 |
| Smoking status | 82.99 | 201 | | | | |
| Never smoked | 44.80 | 105 | 2.34 | 1.00 | – | – |
| Currently smoked | 23.17 | 59 | 2.55 | 1.09 | 0.78 | 1.51 |
| Previously smoked | 15.02 | 37 | 2.46 | 1.05 | 0.70 | 1.54 |
| Weekly aerobic activity | 32.20 | 100 | | | | |
| <3 h/week | 17.63 | 55 | 3.12 | 1.00 | – | – |
| ≥3 h/week | 14.57 | 45 | 3.09 | 0.99 | 0.65 | 1.50 |
| Weekly hand intensive activity (non-occupational) | 42.56 | 145 | | | | |
| <3 h/week | 11.73 | 53 | 4.52 | 1.00 | – | – |
| ≥3 h/week | 30.83 | 92 | 2.98 | 0.66 | 0.47 | 0.94 |

*Medical condition includes diabetes mellitus, rheumatoid arthritis, thyroid disease and pregnancy. There were no pregnant women who became cases.
DUE, Distal upper extremity; MSD, Musculoskeletal disorder

deviations in wrist posture. Future analyses of our pooled cohort will assess the role of workplace biomechanical factors on CTS incidence and their relationship with gender.

There is growing interest in how to accommodate an aging workforce as the demographics of the Western working population change. We found an approximately linear relationship between age and increased risk for CTS among the pooled cohort across the entire working age range (through the sixth decade). Mondelli *et al*[5] identified a peak risk in women during their fifth decade of life, and a bimodal relationship among men with the highest risk in the fifth and seventh decades of life. Unlike the Mondelli and other studies,[42] the slope and linear relationship that we observed between age and CTS was almost identical when stratified by gender. Apportioning this age-related trend in risk between physiologic changes due to aging and cumulative workplace exposure with increasing years worked is difficult since age and work history duration are highly collinear. Despite this, it is clear that there should be

**Table 4** Multivariable models for selected personal and health-related factors, adjusting for gender, age and BMI

| | n | n (CTS cases) | HR | Lower 95% CI | Upper 95% CI | p Value |
|---|---|---|---|---|---|---|
| Gender* | 3500 | 203 | | | | |
| Male | 1855 | 81 | 1.00 | | | |
| Female | 1645 | 122 | 1.30 | 0.98 | 1.72 | 0.07 |
| Age† | 3500 | 203 | | | | |
| <30 years of age | 1084 | 31 | 1.00 | | | |
| ≥30 and <40 years of age | 832 | 47 | 2.12 | 1.34 | 3.34 | 0.00 |
| (>=40 and& <50 years of age | 930 | 69 | 2.84 | 1.85 | 4.37 | 0.00 |
| (>=50 years of age | 654 | 56 | 3.04 | 1.96 | 4.71 | 0.00 |
| BMI‡ | 3495 | 203 | | | | |
| BMI <30 kg/m$^2$ (normal or overweight) | 2321 | 104 | 1.00 | | | |
| BMI ≥30 kg/m$^2$ (obese) | 1174 | 99 | 1.67 | 1.26 | 2.21 | 0.00 |
| General health | 2058 | 160 | | | | |
| Excellent to very good | 891 | 55 | 1.00 | | | |
| Good | 890 | 83 | 1.71 | 1.21 | 2.42 | 0.00 |
| Fair or poor | 277 | 22 | 1.52 | 0.91 | 2.54 | 0.11 |
| Medical condition§ | 3495 | 203 | | | | |
| No medical condition | 3150 | 175 | 1.00 | | | |
| Medical condition | 345 | 28 | 0.95 | 0.62 | 1.44 | 0.79 |
| Diabetes mellitus | 3197 | 190 | | | | |
| No diabetes | 3075 | 183 | 1.00 | | | |
| Diabetes | 122 | 7 | 0.64 | 0.30 | 1.40 | 0.27 |
| RA | 3375 | 197 | | | | |
| No RA | 3309 | 191 | 1.00 | | | |
| RA | 66 | 6 | 1.13 | 0.50 | 2.57 | 0.77 |
| Thyroid disease | 3487 | 201 | | | | |
| No thyroid disease | 3328 | 185 | 1.00 | | | |
| Thyroid disease | 159 | 16 | 1.24 | 0.72 | 2.12 | 0.44 |
| Gout | 3196 | 189 | | | | |
| No gout | 3155 | 183 | 1.00 | | | |
| Gout | 41 | 6 | 1.57 | 0.72 | 3.44 | 0.26 |
| Previous DUE MSD¶ | 2845 | 157 | | | | |
| No previous DUE MSD | 2550 | 126 | 1.00 | | | |
| Previous DUE MSD | 295 | 31 | 1.58 | 1.05 | 2.37 | 0.03 |
| Weekly aerobic activity | 1574 | 99 | | | | |
| <3 h/wk | 1030 | 55 | 1.00 | | | |
| ≥3 h/wk | 544 | 44 | 0.82 | 0.55 | 1.22 | 0.32 |
| Weekly hand intensive activity (non-occupational) | 2112 | 144 | | | | |
| <3 h/wk | 720 | 53 | 1.00 | | | |
| ≥3 h/wk | 1392 | 91 | 0.58 | 0.41 | 0.82 | 0.00 |

*Adjusted for age and BMI only.
†Adjusted for gender and BMI only.
‡Adjusted for age and gender only.
§Includes diabetes mellitus, rheumatoid arthritis, thyroid disease, pregnancy.
¶Includes wrist tendinitis, elbow epicondylitis and trigger finger.
BMI, Body mass index; DUE, Distal upper extremity; MSD, Musculoskeletal disorder; RA, Rheumatoid arthritis

awareness of the increased risk of CTS among older workers as well as efforts to identify effective prevention strategies for the older worker.

Similar to the general population, obesity poses an emerging health risk among Western workers. Previous studies have shown varying strengths of association between obesity and CTS with risks ranging from 1.5[7] to 2.5.[44 45] Our analysis was comparable, and when BMI was assessed as a continuous variable, a near-linear trend for increasing risk of CTS was evident up to 45 kg/m$^2$, after which data became sparse. The mechanism by which BMI contributes to risk for CTS is not well understood.[44] Among other important health considerations, it appears that interventions addressing obesity may also have a positive impact on incidence of CTS. Further analysis of obesity and physical workplace exposures in this prospective study may help focus such programmes on those who are at the greatest overall risk.

Medical conditions, such as diabetes mellitus, rheumatoid arthritis, gout and thyroid disease have been linked to CTS in previous studies.[22 45] In this cohort, the higher incidence rate for those with diabetes mellitus, rheumatoid arthritis and thyroid disease, disappeared after adjusting for age, gender and BMI, indicating that these conditions were not independent predictors of CTS in this cohort. However, if subjects with these chronic conditions, who develop CTS, are more likely to leave employment, then only their less susceptible coworkers would

**Table 5** Multivariable models for workplace factors, adjusting for gender, age and BMI

| | n | n (cases) | HR | Lower CI | Upper CI | p Value |
|---|---|---|---|---|---|---|
| Years worked at company for entire cohort | 3480 | 200 | | | | |
| ≤3.5 years | 752 | 25 | 1.00 | | | |
| >3.5 years and ≤7 years | 1299 | 64 | 0.63 | 0.39 | 1.03 | 0.06 |
| >7 years and <=15 years | 881 | 69 | 1.04 | 0.62 | 1.73 | 0.89 |
| >15 years | 548 | 42 | 0.86 | 0.49 | 1.50 | 0.59 |
| Years worked for recent hires (<1 year) | 1234 | 41 | | | | |
| >3.5 years | 719 | 23 | 1.00 | | | |
| ≤3.5 years | 515 | 18 | 3.08 | 1.55 | 6.12 | 0.001 |
| Job strain | 1549 | 102 | | | | |
| Low job strain (low demand and high control) | 423 | 23 | 1.00 | | | |
| Active (high demand and high control) | 307 | 24 | 1.48 | 0.83 | 2.66 | 0.18 |
| Passive (low demand and low control) | 360 | 19 | 1.23 | 0.67 | 2.27 | 0.50 |
| High job strain (high demand and low control) | 459 | 36 | 1.86 | 1.11 | 3.14 | 0.02 |
| Social support | 1568 | 49 | | | | |
| Low support | 677 | 28 | 1.00 | | | |
| High support | 891 | 21 | 0.54 | 0.31 | 0.95 | 0.03 |
| Physically exhausted | 901 | 160 | | | | |
| None to slightly physically exhausted | 133 | 83 | 1.00 | | | |
| Moderate to severely physically exhausted | 768 | 77 | 1.45 | 1.05 | 2.00 | 0.03 |
| Mental exhaustion | 2153 | 163 | | | | |
| None to slightly mentally exhausted | 1607 | 109 | 1.00 | | | |
| Moderate to severely mentally exhausted | 546 | 54 | 1.34 | 0.96 | 1.87 | 0.08 |
| Job satisfaction | 3080 | 181 | | | | |
| Very satisfied | 1170 | 58 | 1.00 | | | |
| Satisfied | 1505 | 100 | 1.43 | 1.03 | 1.99 | 0.03 |
| Dissatisfied or very dissatisfied | 405 | 23 | 1.28 | 0.79 | 2.08 | 0.31 |

BMI, Body mass index.

be included in this study. Such self-selection out of the workforce is consistent with the relatively low baseline prevalence for diabetes mellitus in this cohort (4.3%) relative to the general working population (10.0%).[46]

There have been inconsistencies in the associations reported between smoking and CTS. Geoghan *et al*[26] found no association with smoking and CTS, and other studies found a slight increase in risk for those who ever smoked.[7 47] In this pooled cohort, neither current nor previous smoking status was significantly associated with an increased risk of CTS.

The results in this analysis are consistent with previous observations that distal upper extremity disorders, such as fractures[26] and wrist tendinitis,[7 40] are associated with increased risk for CTS. This may be due to the disorders having similar biomechanical risk factors, or an increased susceptibility of individuals not fully recovered from a previous musculoskeletal disorder.

The finding that hand-intensive activities outside of work at baseline were associated with reduced risk of developing CTS, should be interpreted with caution. Although the temporal relationship is unclear, individuals with periodic median nerve symptoms or those exposed to high biomechanical risk factors might choose not to engage in hand-intensive activities outside of work. Future analysis of hand-intensive activities stratified by occupational biomechanical exposure levels may help clarify this hypothesis.

It has been shown that when prospective studies include workers hired well before study enrolment, exposure–response results may be attenuated.[36] The bias occurs because only the workers who remain at work without prevalent disease are eligible for enrolment in a prospective incidence study. In this pooled study, approximately 25% of the cohort was hired within a year of recruitment. We therefore examined associations between work years and CTS incidence in the subset of recent hires. Among those recently hired (ie, less than 1 year), there was a substantial increase in risk associated with working less than 3.5 years compared with those working more than 3.5 years. Also consistent with a survivor bias, was the inverse trend seen for those with long seniority, but the association was attenuated (closer to the null).

High job strain was also associated with increased risk for CTS. This is consistent with findings by Silverstein *et al*[15] who reported that those who developed incident CTS had significantly higher psychosocial job demands at baseline. Of equal interest, both supervisor support and coworker support were strongly protective for CTS. Silverstein *et al*[15] did not report a significant difference in social support between those who developed CTS and those who remained asymptomatic. It is possible that those with high job strain or low social support have increased physiological stress placing them at higher risk for developing CTS. Alternatively, it is possible that reporting thresholds are affected by these psychosocial factors. Further analysis of this cohort will assess whether physical exposures at work alter the relationship between job strain, social support and CTS.

## Limitations

Despite the increased power and generalisability of the pooled study findings, there were limitations. First, there were some differences in study design among the six studies that presented challenges when pooling the data.[9] Consistent with the population study by Nathan *et al*,[48] a large percentage of our subjects met the criteria for median mononeuropathy at baseline, but remained asymptomatic throughout the study. This supports previous recommendations that CTS diagnosis include both median nerve symptoms and prolonged median nerve latencies.[32] Data on some medical conditions are likely underpowered. Some studies did not collect the data necessary to generate psychological demand and decision latitude subscale scores, therefore, the sample size was reduced by approximately half for the job strain and social support findings. The sample size was also smaller for some of the non-occupational activities. Additionally, it should be noted, that as in most occupational studies, years worked was based on the company start date, and did not reflect time spent working in the same or similar industry at a prior employer. Finally, because the study cohort is primarily comprised of non-recent hires, it represents a less susceptible survivor population that may lead to an underestimation of associations.

## CONCLUSION

Female gender, older age and higher BMI were associated with CTS incidence in this broad-based worker cohort. High job strain increased risk, and high social support was protective. Further analysis will identify the biomechanical risk factors associated with CTS and clarify possible interactions between occupational psychosocial factors, personal factors, and workplace physical exposures.

### What this paper adds

- CTS is an important driver of workers compensation costs, lost time, lost productivity and disability.
- To date, few large prospective studies using rigorous case criteria, individual-level exposure data and appropriate control for confounding by personal factors have examined associations between occupational psychosocial and biomechanical risk factors and CTS incidence.
- Personal factors associated with an increased risk of developing CTS were BMI, age and being female.
- Workplace risk factors were high job strain while social support was protective.

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# Personal and workplace psychosocial risk factors for carpal tunnel syndrome: a pooled study cohort

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